

The University of Chicago

GEOLOGY AND PETROGRAPHY OF
THE TOBACCO ROOT MOUNTAINS
MONTANA

A PART OF A DISSERTATION SUBMITTED
TO THE FACULTY OF THE DIVISION OF
THE PHYSICAL SCIENCES IN CANDIDACY
FOR THE DEGREE OF DOCTOR OF
PHILOSOPHY

DEPARTMENT OF GEOLOGY AND PALEONTOLOGY

1933

By
WILFRED TANSLEY

Private Edition, Distributed by
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STRATIGRAPHIC GEOLOGY

Pre-Cambrian

General Statement

Whether considered from the standpoint of areal distribution, economic significance, or scientific interest the pre-Cambrian formations are the most important in this district. They occupy approximately 1/3 of the total area, considerably more than any other group of rocks; they present a greater number and a wider variety of problems; and except for the gold won from placers, they are responsible for practically the total production of metal.

These formations have been divided into two groups, Belt and pre-Belt rocks. The pre-Belt rocks are subdivided into the early pre-Belt or Pony series, and later pre-Belt or Cherry Creek series. Rocks of the Belt series occupy only a relatively small area, but are not lacking in interest as they contain the oldest unaltered sediments in the district, conglomerate and arkose of Algonkian age.¹ The Cherry Creek series consists of highly metamorphosed sediments and the age assigned to the type section is Algonkian.² The Pony series consists principally of gneisses which have been placed in the Archean.³ Although the Cherry Creek series is of sedimentary origin and has been assigned to the same time division as the Belt rocks it is certainly much more closely related to the Pony series than to the Belt. It is the opinion of

¹A. C. Peale, U. S. Geological Survey, Geol. Atlas, No. 24, 1896.

²Ibid.

³Ibid.

the writer that, with the exception of the Belt, the only safe statement which should be made regarding these formations is that they are pre-Cambrian and that the Cherry Creek and Pony series are older than the Belt.

Pony Series

Name.- Gneisses and schists of this group, although covering many square miles, have not been given any particular name, but have been referred to simply as Archean. They are well represented on the east side of the range in the Pony district and the name Pony series is suggested.

Distribution.- The Pony series is continuously exposed for more than twenty miles on the northwest, north, and east sides of the batholith which forms the central core of the range. Exposure on the southeast and south sides of the batholith are interrupted by overlying patches of Tertiary sediments and Pleistocene glacial deposits. Its widest expanse is in the eastern section on a line joining Pony and Norris, and from the latter point it continues to the eastward of the area mapped.

Character.- The series consists entirely of gneisses and schists and, of course, exhibits all the general characteristics of metamorphic rocks of this type. Gneisses are much more common than typical schists.

In general the gneisses are rather monotonous in character, but in detail considerable difference in lithology is seen over short sections. The color may be pink or gray, the grain size fine or coarse, and the banding wide or narrow. These variations occur within short distances, again and again, so that on the whole one is impressed by a certain sameness. However, the general distinction can be made that in the lower part of the series, which is close to the batholith, a pinkish feldspar-quartz-hornblende

gneiss is very common while higher up in the series gray gneisses are much more common.

More variation in character is apparent when the rocks are examined in thin section. Quartz, showing undulatory extinction and drawn out by metamorphism, is usually the most abundant constituent. The feldspar is most frequently a medium plagioclase, either oligoclase or andesine. Microcline is more abundant than orthoclase, though both may be absent, but the combined total rarely exceeds the lime-soda feldspar in amount. White mica is common as an alteration product of the feldspar. The mafic minerals are hornblende and biotite, both usually being present, one generally in much larger amount than the other. Both are attacked by scaly patches of chlorite. Magnetite and apatite, and in some specimens small red garnets, are present as accessory constituents.

Distinct textural varieties of gneiss occur, such as banded gneiss, lenticular gneiss, and augen gneiss. No particular type is limited to any one section and two or more types may occur within a few feet of each other. Banding is the most distinctive feature of a gneissic rock and the banded type occurs everywhere throughout the series. A specimen collected on South Boulder Creek, about 200 yards above the Mammoth dam, was examined in thin section. The color of the freshly broken surface is light gray, having a sort of salt and pepper appearance, but the weathered surface is darker and is often quite rough due to resistant quartz grains standing out in relief as erosion proceeds. The average size of individual grains composing the rock is about five millimeters. Banding is prominent and of a wavy character with the width of individual bands varying from 10 millimeters to 25 millimeters. Any band when traced along its length shows more or less variation in mineral content and no one band can be traced for

half a meter without feathering out. The mineral constituents, with approximate percentages, are Quartz (35 %), Andesine (25 %), Orthoclase (10 %), Microcline (2 %), Biotite (20 %), Hornblende (5 %). The remaining 3 % is made up of the following accessory constituents given in the order of abundance: apatite, magnetite, garnet, and zircon.

Coarser varieties are also common to which the above description would apply except for the size of constituent grains and width of individual bands. There is no definite relation between the size of grain and width of banding. The width of separate bands does not often exceed 10 centimetres and even in these relatively thick bands the average size of individual grains may not be more than 5 millimeters.

The lenticular type, while occurring at many points, was particularly noted northeast of Lake Shore Peak at the head of South Boulder Creek, and also on the ridge between Pony and Charcoal creeks about three miles west of Pony. A sample collected at the latter point shows dark lenticles, composed of hornblende, measuring from one to two centimetres in length, surrounded by light colored bands composed of quartz and feldspar in nearly equal amounts. These features impart a flecked appearance to the rock. These lenticles probably represent sheared phenocrysts which have been drawn out by movement. When viewed in three dimensions they do not appear as bands and when cut at right angles to their long axis they show an approximately equidimensional cross-section.

Sporadic porphyroblasts are of frequent occurrence in most of the gneisses but rarely become so numerous as to warrant calling the rock an augen gneiss. However, about a mile northeast of Lake Shore Peak there is an exposure of this rock. The augen vary

in size from about one to ten centimetres taken along the least diameter. They are composed of feldspar or feldspar and quartz with or without a little garnet. Very often a rim of crushed quartz lies between the feldspar and the gneissic ground mass.

As in most areas of ancient metamorphic rocks gradations are found between gneiss and schist. In this district gneiss predominates. The only typical schists noted were amphibolite, having common hornblende as the chief constituent, and a quartz-biotite schist.

On Pony Creek, west of the town of Pony, amphibolite schists are interbedded with gneisses. The composition averages hornblende (70 %), quartz (20 %), and plagioclase feldspar (10 %). The hornblende crystals are arranged in subparallel orientation in one plane and it is to this arrangement that the rock owes its capacity to split readily in one direction. The quartz has also assumed a tabular character due to recrystallization under directive pressure. The grain is finer and the banding less prominent than in most gneisses. Banding is due to the dark colored constituents being relatively more abundant in some layers than in others and not to any mineralogical dissimilarity of individual layers.

Because of the highly metamorphosed condition the original character has been greatly obscured and although a small amount of sediment may have originally been present almost all the gneiss is believed to have been derived from igneous rock. In addition to presenting a decidedly igneous aspect, definite intrusive relations were observed at some points. About eight miles from Ennis, on the highway to Virginia City, there are exposures of granite gneiss which intrude hornblende-mica schist. None of the rocks are highly quartzose nor particularly rich in aluminous minerals as would be expected of altered sediments. When examined

from a distance of a few feet an outcrop may appear distinctly banded, whereas, on closer inspection, the bands grade into each other, and none are continuous for any distance but feather out rapidly.

Structure.- The development of schistose and gneissic structures has been noted and in general trend these conform roughly to the northern boundary of the intrusive. Dips measured on the schistosity range from 30 to 90 degrees, inclined to the north and west, the steeper dips being more common. Any increased steepening of dips toward the periphery of the batholith is rare.

Although it is slightly beyond the limits of the area described, the canyon of the Madison River, three miles east of Red Bluff, offers an excellent opportunity to observe the complicated structure common to the rocks of this series. Here, exposed on sheer walls more than 1000 feet in height, may be seen marvellously contorted gneisses, faulted, folded, and squeezed in almost every conceivable manner.

Economic significance.- Mineralization is widespread throughout the area and rocks of this series are host to important mineral deposits from which a large proportion of the gold production has come. The veins at the two largest and most important mines of the district are in Pony gneiss.

Cherry Creek Series

Name.- On the east slope of the Gravelly Range, which is the southern continuation of the Tobacco Root Range, there occurs a series of metamorphic rocks which were separated by Peale in 1896, and as they are particularly well exposed on Cherry Creek he chose that name for the series and referred it to the Algonkian

period.¹ In this he was followed by Van Hise² and later by Blackwelder.³ Similar rocks occurring in the southwest section of the Tobacco Root Range are to be correlated as part of the Cherry Creek series.

Description of the Type Cherry Creek Section.- With the exception of a brief account of these rocks by Runner and Thomas⁴ the only description is that given by Peale at the time he named the series, and it is here quoted in full.

The Cherry Creek beds consist of a series of marbles, or crystalline limestones, and interlaminated mica-schists, quartzites, and gneisses, well shown southwest of Madison Valley. They are all highly inclined and are perfectly conformable to one another, occupying an area of 30 to 40 square miles in the foothills immediately west of the Madison River, a few miles north of the southern boundary of the mpa. They are folded, but the folds are somewhat obscure, so that it is impossible to estimate accurately the total thickness, but it is certainly not less than several thousand feet. A limited area of these beds occurs on the east side of the Madison Valley at the western edge of the Madison Range. Between Cherry Creek and Wigwam Creek, on the west side of the Madison Valley, the unchanged beds of the Cambrian rest upon the up-turned edges of this group.

Cherry Creek and Morgan Creek are two tiny streams, about $3\frac{1}{2}$ miles apart, flowing eastward toward the Madison River. Near Cherry Creek the rocks strike northeast but northward toward Morgan Creek they swing sharply into a north-south trend. The general dip is west at angles of 45 to 80 degrees, but dips and strikes may vary widely from this because of local folding. In passing westward across the strike of the beds for $3\frac{1}{2}$ miles up Cherry Creek one finds successive exposures of dark gray horn-

¹A. C. Peale, U. S. Geol. Survey, Geol. Atlas, No. 24, 1896.

²Van Hise and Leith, "Pre-Cambrian Geology of North America," U.S. Geol. Survey, Bul. 630, p. 864.

³Handbuch der Regionalen Geologie, Heidelberg, 1912. U.S. of North America by E. Blackwelder, VIII Band., Abt., 2, p. 131.

⁴J. J. Runner and L. C. Thomas, "Stratigraphic Relations of the Cherry Creek Group in the Madison Valley, Montana," B.G.S.A., Vol. 39, 1928, p. 202.

blende schist, light gray quartz-mica schist, buff quartzite, white crystalline limestone, dark gray quartz-biotite schist, and pink feldspar-quartz gneiss. The gneissic member at the top of the series is the thickest, although the upper contact was not seen. The limestone member is estimated by pacing to be more than 1200 feet thick. Quartzite having a total thickness of perhaps 200-300 feet is interbedded with the lower part of the limestone. There is repetition by folding, and perhaps also by faulting, making the true thickness of the section difficult to ascertain, but it is probably between 6000 and 7000 feet.

Distribution.- In the Tobacco Root area from Alder Gulch south of Virginia City, to Wisconsin Creek north of Sheridan, a distance of more than 20 miles, these rocks are exposed over a width of five to ten miles. They are limited on the west by Tertiary lake beds and on the east by the early pre-Belt rocks. For the most part this series is confined to the west side of the range and crosses the main crest line at only a few places. South of Virginia City, in the region of Old Baldy Mountain, these rocks apparently pass beneath the Paleozoic cover to reappear again about seven miles east on Wigwam Creek from which point they can be traced without interruption to the type section on Cherry Creek.

Character.- The Cherry Creek series exposed in the Tobacco Root area contains the same lithological units and exhibits the same complicated structure as in the type section, but in the area mapped it will be separated into three divisions.

The lowest division is a garnetiferous schist; the middle division consists of quartzite and limestone, and the upper division of quartz-hornblende-biotite schist, and granite gneiss. Of the three units the upper is by far the thickest, but the lime-

stone of the middle division is the most persistent member. Not all are present everywhere, but garnet schist and limestone are usually associated, almost invariably so in the northwest portion of the area. The quartzite and crystalline limestone become thinner toward the northwest, and quartzite beds are practically absent northwest of Mill Creek, being represented only by lenses up to five feet in length, in the limestone. These are well shown about a half mile west of Leggat Peak.

With the exception of the garnetiferous schist, which is absent in the type section, the rocks of the two districts appear identical in the field. Quartz-feldspar gneiss lies at the top of the series and is the thickest member at both places. Limestones and quartzites are considerably thicker in the type section but, as already noted, this is because of a gradual thinning toward the north.

Garnetiferous schist, though well exposed at several points, is best developed in the northwestern section on upper Indian and Wisconsin creeks. Being no more resistant than the adjacent rocks it forms no particularly prominent outcrops, but it is easily recognized because of the high garnet content and the tendency to weather to a dark brown color. The garnets vary widely in both size and amount. From 20 to 60 per cent of the rock may be made up of garnet ranging in size from a small fraction of an inch to four inches in diameter. They are usually irregular in shape, but the characteristic dodecahedral habit can be recognized and only the small ones possess the clear, deep red color and vitreous lustre of those collected by placer miners from the Ruby River sands. The large garnets found only in proximity to the granite are impure and have a dull, grayish-red color.

A large garnet, collected from an exposure on upper Indian

Creek about a mile west of the Sunbeam mine, was broken and a chip obtained from the centre of the crystal examined in thin section. The slide contains about 70 per cent garnet and 25 per cent quartz, the remainder being mostly magnetite. A little orthoclase feldspar was recognized and some small fragments of an altered, unidentified ferromagnesian mineral. Although minute rounded quartz anhedra occur scattered irregularly throughout the garnet, much of the quartz occurs in streaks traversing it. These streaks are roughly parallel, the quartz fragments in them are arranged with their long dimensions parallel to the streak, many of them showing undulatory extinction. The garnet has not been fractured and quartz later introduced; but the structure is relict from the original schist which has been enclosed by the growing garnet. Another thin section from the outer part of the same large crystal exhibits similar structures.

In contrast, garnets which were collected some distance from the granite contact are either entirely free from quartz inclusions, or have nuclear portions full of residual inclusions while the marginal parts are entirely clear. This quartz is residual and represents material which could not be incorporated in the garnet as it grew under conditions of dynamic metamorphism.

The remainder of the rock consists mostly of quartz and biotite. A little hornblende may be present, but it seldom amounts to 5 per cent. Near the granite contact, where the large garnets occur, hornblende is entirely absent. It has been changed by thermal metamorphism to biotite and magnetite, the excess silica combining with potash to make feldspar and any remainder deposited as quartz. This is not unusual in cases of multiple metamorphism, where thermal action has altered rocks already changed by dynamic

forces.¹

It is not due to any lack of intensity in metamorphic conditions that such minerals as andalusite, cordierite, and sillimanite are rare but to a deficiency of alumina in the original sediment.

Although foliation is usually absent, or poorly marked, schistosity is well developed. Garnets are scattered irregularly throughout the mass, but biotite has a notably parallel arrangement both in the hand specimen and thin section, although it shows no tendency to concentrate in layers.

At the base of the limestone on Harris Creek, three miles northeast of Laurin, the garnetiferous rock is foliated. Alternate layers, with slight color difference, about five millimeters in width, are separated by layers of red garnets, less than one millimeter in diameter. When fractured, the rock breaks along the garnet layers. Distribution of material in the original sediment is certainly responsible for the unusual arrangement of the garnets.

Of the middle division of the Cherry Creek series, the limestone is by far the thickest and most persistent member. It occurs in bands traversing the area in a contorted pattern which reflects the general structure. These limestone belts are locally termed "lime dikes." Any rock forming a conspicuous band, regardless of its relation to adjoining rocks, is likely to be termed a dike by prospectors.

The limestones are white, cream, dark gray, or greenish-blue in color. All varieties weather similarly to a light brown color having a patchy or velvety sheen which renders them distinct

¹Alfred Harker, Metamorphism, 1932, pp. 322-330.

from adjacent schists even when viewed from a distance. They are usually coarsely crystalline and cleavage surfaces on individual calcite grains will sometimes measure $3/8$ inch. The more coarsely crystalline types are most often found where deformation has been greatest, as at the crests of sharp folds.

Impurities are common but are not usually present in sufficient amount to cause gradation to another rock type. However, on the ridge between Harris and Bivins gulches, about four miles northeast of Laurin, a limestone bed gradually passes, in a quarter of a mile, into a rusty weathering chert with iron and silica.

Different mineral species found in the crystalline limestone include plagioclase, garnet, tremolite, hornblende, biotite, tourmaline, wollastonite, olivine, epidote, zoisite, and quartz. Any of these minerals may occur in small amounts in any limestone bed but they are more numerous near the granite although limestone and granite were not found in actual contact. Metallic minerals, pyrite, chalcopyrite, magnetite, galena, and sphalerite are found in ore deposits associated with the limestone. Graphite is everywhere present as tiny flakes irregularly scattered through the rock. A few unusually large flakes, found in limestone at the Red Pine Mine, have a diameter of one centimetre.

On Davy Creek, six miles south of Alder and close to the highway, there is an exposure of coarsely crystalline limestone which has greenish-blue bands about an inch wide alternating with much wider white bands running parallel to the bedding. Examination under the microscope shows that the greenish-blue color is due to a relatively high concentration of olivine, amounting to about 20 per cent. The olivine, which occurs in irregular clusters, is much altered to serpentine along the cracks and edges. Surrounding the narrow serpentine rim there is often a partial

border of magnetite and almost invariably an outer border of needle-like crystals which were not positively identified but believed to be tremolite. The remainder of the rock is calcite with a few shreds of phlogophite.

One of the best exposures, and fortunately one of the most readily accessible, occurs just east of Laurin. The width of outcrop varies from 2000 feet, where it has been thickened on the crest of a fold, to less than 100 feet where drawn out on the limbs. The true thickness is estimated to be nearly 1000 feet.

The quartzite member occurs interbedded with the limestone but is not nearly so persistent. It is a white to light gray, fairly pure variety, usually massive or with ill defined bedding. The quartzite is somewhat more resistant to erosion than the limestone and may, as in the section east of Laurin, outcrop slightly above the general surface.

Individual grains composing the rock appear well rounded, although some are drawn out by metamorphism. They are of fairly uniform size, averaging about two millimetres in diameter. Examination with a hand lens, on a freshly fractured surface, usually reveals only quartz grains fitting together as a mosaic, but in some specimens the grains are surrounded and cemented by a thin film of yellow iron oxide.

A sample of quartzite, collected 1.5 miles east of Laurin was examined in thin section. Quartz, fine scales of white mica, and a little yellow iron oxide are the only constituents present. Many of the quartz grains have lost their rounded outline and have developed serrated edges so that crystals interlock with very little cementing material.

In the Laurin section the quartzite is from 50 to 100 feet thick, but northward it becomes much thinner. Except for small

lenses occurring within the limestone it is practically absent north of Mill Creek. These lenses are well shown about $\frac{1}{2}$ mile west of Leggat Peak.

The upper division consists of quartz-hornblende schist, quartz-biotite schist, and quartz-feldspar gneiss, each of which grades into the other through several intermediate types. They are interbedded and may all occur in a section a few feet thick, although the gneiss forms the major part of this division. Banding is well defined in all these types and if the rock is not much contorted, the bands may be continuous for several feet.

The quartz-hornblende type is the more common variety of schist. Hornblende is present in both varieties but biotite may be entirely absent. The biotite type is generally more coarsely banded and also of coarser grain, but due to the nature of biotite it produces a much higher degree of schistosity.

In thin section the quartz usually exhibits strain effects and has inclusions of apatite, but otherwise presents no noteworthy features. The feldspar of the gneiss is a medium plagioclase with microcline and a small amount of orthoclase. Potash feldspar seems uncommon in the schists. The biotite is the ordinary golden brown variety sometimes altered to epidote. The hornblende of the biotite schist usually has the very bright green color common to amphiboles found in sodic varieties of igneous rocks and usually shows some change to chlorite. Magnetite and apatite are always present.

The thickness of this division is not known, but it is to be thought of in terms of thousands rather than hundreds of feet. It is best exposed on Horse Creek and Mill Creek where deep gulches have cut across the strike of the rocks.

In contrast to the Pony series, the Cherry Creek rocks

are undoubtedly of sedimentary origin. Lithologically the two groups are widely dissimilar. Limestones and quartzites are entirely absent from the Pony series, nor is garnet schist known to occur in it. Amphibolite and quartz-biotite-hornblende schists, it is true, occur in both groups but are very much more common in the younger series. Although chemical analyses are not available the percentage of quartz seems, in general, to be higher in the Cherry Creek rocks. The only pre-Cambrian intrusives found to cut the younger series were basic dikes.

The limestones and quartzites are certainly of sedimentary origin and interbedded schists, which have caused no thermal metamorphism, must be the same. In the lower tunnel of the Red Pine mine, on Indian Creek, about 1700 feet from the portal, limestone interbedded with amphibolite-garnet schist is beautifully exposed. The contact is very sharp; lime silicates have not been developed nor is there the slightest suggestion of igneous metamorphism. (Pl. 5, fig. B). This is in marked contrast to the statement of Runner and Thomas:¹

Banded amphibolite garnet rocks pass by insensible gradations, on the one hand into granite and, on the other, into crystalline limestone.

This description was written of the type Cherry Creek area, but neither here nor in the Tobacco Root area did the writer notice a single instance of any such gradation. The limestone contacts are always remarkably sharp.

Banding in both gneiss and schist is frequently regular and continuous for considerable distances. The transition from dark bands consisting of predominating dark silicates, to lighter ones containing quartz and feldspar, is so sharp that it seems im-

¹J. J. Runner and L. C. Thomas, "Stratigraphic Relations of the Cherry Creek Group in the Madison Valley, Montana," B.G.S.A., Vol. 39, 1928, p. 202.

possible to account for them except by changes in sedimentation. The writer is not aware of any igneous process which will produce fine, sharply defined, regularly alternating bands of predominantly light and dark minerals in a rock. In all the Cherry Creek series no facies ever was observed to transect any other.

This group represents original deposits of limestone, sandstone, shale, and arkose which have been subjected to regional metamorphism producing the various types now exposed. Igneous metamorphism has played but a very minor part. The Cherry Creek series is by no means to be correlated with the Belt series to be described later; it is entirely different in degree of metamorphism, attitude, and lithology.

Structure.- The Cherry Creek rocks were once nearly flat-lying beds deposited in a broad basin, but they have since been squeezed into a closely folded syncline where the common attitude is more nearly horizontal than vertical. From Virginia City to Sheridan a general northeast strike is maintained, but there are many variations because of local folding. About two miles southeast of Ruby one may trace a limestone bed along the limb of a fold to return on the other limb within less than half a mile of the starting point.

Economic significance.- A considerable quantity of gold has been obtained from veins located in Cherry Creek rocks, and several active mines in the Sheridan district are in quartz veins associated with limestone. A great number of prospect holes, showing mineralization have been dug along the limestone belts.

Evidence of Unconformity between Pony and Cherry Creek Series

It has already been noted that others have placed the group here referred to as the Pony series in the Archean, and the Cherry Creek series in the Algonkian, and this was done without

mention of an unconformity, whereas Archean and Algonkian rocks described elsewhere are separated by a marked angular unconformity. It is quite possible that the two series are here separated in this manner and that the field evidence for it has been obscured by intense dynamic metamorphism or by igneous intrusion.

About five miles west of Ennis, and again near Lake Shore peak, in the Tidal Wave district, the Pony and Cherry Creek series are in contact, but a sharp line cannot be drawn between them. However, at some distance on either side of this contact zone the difference in character of the two series is apparent.

On South Boulder Creek, about three miles above the Mammoth mine, boulders were found showing two ages of metamorphic rock. One boulder, measuring about 15 feet in diameter, contains a rounded fragment of gneiss about $2\frac{1}{2}$ feet across, surrounded by a matrix of schist. Examination of the inclusion in this section shows it to be a granite gneiss, identical with much of the Pony gneiss, containing quartz, feldspar, hornblende, and a little biotite. The texture is typically gneissoid and no unusual features are exhibited. The matrix is an ordinary quartz-biotite schist. The orientation of the gneissic banding lies at a sharp angle to that of the enclosing schist. (Pl.4, fig. B) Clearly, two distinct periods of pre-Belt folding are represented. Boulders of similar character were found in the cirque at the head of North Meadow Creek, and again on Wisconsin Creek, about a mile below the Leiter mine. These locations are of some significance as, in each case, the rocks may readily have come from points along the boundary line of the two series.

These erratics may be remnants of a conglomerate, containing fragments of the Pony gneiss, which was metamorphosed at the close of Cherry Creek time, and they suggest that a gneiss, once

formed, may remain stable under considerable stress. The relative degrees of metamorphism necessary to produce schists and gneisses may also be inferred. When a quartz-biotite schist can be produced without any apparent alteration of an included gneissic pebble, the amount of stress necessary to produce the latter must be of a much higher order. A gneissic pebble may evidently pass through more than one period of deformation, still preserving the structure first imposed upon it, and without revealing its previous metamorphic history.

While studying a pre-Cambrian conglomerate, which at some points is highly metamorphosed, Dr. F. J. Pettijohn found pebbles, elongated by pressure, in which the gneissic banding lay at an angle to the long dimension of the pebble, indicating that it was an inherited structure preserved throughout intense metamorphism.¹

Belt Series

The Belt series was named by Walcott² from rocks studied in the Belt Mountains of Central Montana.

In the Tobacco Root Mountains these rocks are exposed over only a few square miles in the northwestern portion, but east and north of the area mapped they are much more extensive.³

They are the oldest unaltered sediments of the region and consist of dark-colored, well-indurated conglomerates, breccias, and arkoses. According to Peale,⁴ Belt rocks mapped north of the district attain a great thickness (10,000-12,000 feet) and are

¹Personal communication. The formation referred to is described by F. J. Pettijohn, Journ. Geol., Vol. 38, 1930, pp. 568-573.

²C. F. Walcott, Pre-Cambrian Fossiliferous Formations, B.G.S.A., Vol. 10, 1898, pp. 189-244.

³Idem.

⁴Idem.

directly overlain by the Flathead quartzite (basal Cambrian), but a few miles farther south they do not intervene between the Flathead quartzite and the pre-Cambrian gneiss-schist complex. A coarse conglomerate of Belt age, containing boulders over a foot in diameter, is well exposed in the deep canyon of the Jefferson River eight miles west of Sappington, just beyond the northern limit of the area mapped. The interstate highway and railways both pass through the canyon.¹ The beds here are much disturbed by folding and faulting.

So far as known the Belt rocks of this area are non-fossiliferous and only one ore deposit has been located in them; that at the Gold Hill Mine.

Paleozoic

Paleozoic formations occur at the northern, southern, and mid-western extremities of the range. They consist entirely of sediments, the major portion of which is limestone, dipping away from the central core of the range at moderate angles. These, with the overlying Mesozoic formations, formed the domed up cover of the granite batholith and were early subjected to active erosion. Only the widely separated remnants now remain. Although Silurian and Ordovician rocks have not, as yet, been definitely recognized, they may be present for there seems to be complete conformity between all formations from Cambrian to Permian. Excellent exposures of Paleozoic rocks are to be found on South Boulder Creek, and on the north side of Baldy Mountain, south of Virginia City.

The Flathead formation was the earliest Cambrian sediment to be deposited in the district. It consists mostly of a buff-

¹M. R. Campbell, Guidebook of Western United States, Northern Pacific Route, Bul. 611, U.S. Geol. Sur., 1915, pp. 102-3.

colored, massive, highly resistant quartzite, usually outcropping in persistent, prominent bands and forming an excellent horizon marker. The lower portion is conglomeratic, containing well rounded quartz pebbles up to an inch in diameter. It is well exposed in several of the small mine workings east of Twin Bridges. On the southeast slope of Old Baldy Mountain, on Wisconsin Creek, the quartzite contains beautifully preserved ripple markings. In this area it is immediately overlain by a few feet of soft greenish shale containing abundant remains of what appears to be stems or roots. The specimens are cylindrical fragments, from $1/4$ to $1/2$ inch in diameter, and up to a foot in length. Usually a reduction in diameter of these rod-like forms is noticed in a fragment a few inches long, and branching occurs in some. The surface is smooth and devoid of markings. Longitudinal and transverse sections examined under the microscope by transmitted light failed to reveal any structure. The material is very similar to that described by Hall¹ as *Arthropycus harlini*.

Overlying the Flathead formation is the dark bluish-gray Gallatin limestone with characteristic beds of massive, mottled and laminated pebbly limestone, separated by shale beds. These rocks yield trilobites and brachiopods of upper Cambrian age.² At several places metallic deposits of value have been found in Cambrian formations. The Mayflower mine is in Cambrian rocks, as is the ore at Smelter Hill, on Bear Gulch.

Above the pebbly limestone member of the Gallatin lies the dark colored, massive Jefferson limestone of Devonian age. Fossils are rare in most exposures, but lower and middle Devonian forms have been found. The Gallatin and Jefferson limestones form

¹James Hall, Paleontology of New York, Vol. 2, 1852, p. 5.

²A. C. Peale, op. cit.
E. Douglass, Carnegie Mus. Annals, Vol. 3, 1905, p. 416.

the major portion of the steep north-facing wall of Baldy Mountain, south of Virginia City, and here fossil forms are abundant.

The Threeforks formation consists of orange-colored shale and limestone and overlies the Jefferson. It is said to be very fossiliferous in some sections of the Threeforks quadrangle, but it is easily recognized in the absence of fossils by its color and its relation to the thick Madison limestone.

White Madison limestone, of Mississippian age, is the thickest and most prominent of all Paleozoic limestones. It is the "ridge-maker" of the district, forming the tops of hills everywhere. There is an excellent exposure forming a prominent ridge on South Boulder Creek. Fossils are common in this rock.

A conspicuous formation, overlying the Madison, is the Quadrant which is of Pennsylvanian age. Its bright red color renders identification easy.

Permian beds are represented by a limestone formation believed to be the equivalent of the Phosphoria, above the Quadrant.

Mesozoic

Transition from Paleozoic to Mesozoic sedimentation was effected with little disturbance. Triassic beds are absent and the base of the Jurassic is represented by a quartzite of the Ellis formation. It, as well as Cretaceous beds of the Kootenai, Colorado, and Montana formations, is well exposed six miles south of Jefferson Island, on south Boulder Creek. The Kootenai formation consists of sandstone and limestone, while the Colorado above is shale. Above this, and folded with it, is a mixture of mud, tuff, agglomerate, and lava which has been referred to the Livingstone formation by Peale.¹ and which is the earliest indication

¹Op. cit.

of the widespread igneous activity accompanying the Laramide deformation.

Cenozoic

By far the most extensive Cenozoic formations are the Bozeman Lake beds which accumulated in basins formed by the intense Laramide deformation. They consist of poorly indurated clay, sand, volcanic ash, freshwater limestone, and conglomerate distributed along the bench lands of the Ruby, Jefferson, and Madison valleys. Other large patches lie southwest of Sappington, and east of Harrison they continue beyond the area mapped. Near Virginia City, and also on Williams Gulch, these beds outcrop from beneath the thick basalt flows. At many points they have been gently folded or tilted eastward so that they now depart as much as 15 degrees from the horizontal. On Barton Gulch, seven miles south of Alder, there is an excellent section of interbedded conglomerate, limestone, and sand exposed on the north wall of the gulch, having an eastward dip of 12 degrees. Where the conglomerate outcrops on the surface it has been firmly indurated with an impure calcareous cement by caliche action, but ten feet below the surface it disintegrates easily. The sandy layers contain fragments of opalized wood. Two miles east of Laurin coarse conglomerate, with well rounded fragments of gneiss and limestone, up to six inches in diameter, is exposed in a narrow, linear deposit 35 feet thick. It is evidently a Tertiary stream gravel.

Although no fossils were found by the writer in these lake beds, vertebrate remains of upper Oligocene and lower Miocene age have been discovered near Whitehall, in the Jefferson valley, and also in the upper Madison valley. Since the lake beds of the Tobacco Root area are identical in character and have a similar mode of occurrence they are almost certainly of the same age.

mode of occurrence they are almost certainly of the same age.¹

Deposits of Pleistocene age have been distributed as moraines along most of the valleys heading well up into the mountains and also at a few points on the valley floor well beyond the mouths of the present canyons. These have already been referred to in the discussion of glaciation.

Recent deposits of alluvium and stream gravel occur along all streams. The recent gravels of most streams yield gold, and some such as Alder, Bivins, California, and Harris have produced considerable quantities. Others, of which Mill Creek may be cited as an example, have not been worked to any extent due to the presence of large boulders which greatly hinders placer operations.

¹Earl Douglass, "Fossil Mammalia of the White River beds of Montana," Am. Philos. Soc. Trans., new ser., 1902, Vol. 20, pp. 238-279.

Ibid., "New Vertebrates from the Montana Tertiary," Carnegie Museum Annals, Vol. 2, 1903, pp. 145-200.

W. D. Mathew, "The Fauna of the Titanotherium beds at Pipestone Springs, Montana," Am. Mus. Nat. Hist. Bull., Vol. 19, 1903, pp. 197-226.

IGNEOUS GEOLOGY

General Statement

Igneous rocks are well represented throughout the area. The earliest expression of igneous activity is seen in the numerous dikes and sills intruding the Pony series. The later Cherry Creek series has also been invaded, in similar fashion, by igneous material but to a much less extent. In post-Belt time the most important event in igneous history was the intrusion of a quartz monzonite batholith, and the many dikes and sills which differentiated from it, in late Cretaceous or early Tertiary time. Later, in the Tertiary period, andesite, rhyolite, and basalt were extruded and in post Tertiary time there is further evidence of igneous activity in the form of a very thin bed of volcanic dust.

Intrusive Rocks

Pre-Cambrian Intrusives

Everywhere the Pony series is cut by highly metamorphosed dikes and sills which have been folded with the gneisses. Those of basic character, consisting of hornblende with lesser amounts of quartz and feldspar are most common and occur more frequently as sills than as dikes. The acid dikes were intruded as pegmatites and aplites: they are almost entirely devoid of ferromagnesian minerals, consisting only of quartz and cloudy sericitized feldspar. The only metamorphosed rocks intruding the Cherry Creek series seem to be basic dikes and sills, more commonly the latter. (Fig. C Pl. 3.) The fact that the intrusive rocks have concordant more often than cross-cutting relations suggests that igneous activity occurred after gneissic structure had been developed and

that invading material found access less difficult parallel to folia than transecting them.

A most interesting and unusual rock, too small in extent to be shown on the map, occurs on the north side of Copper Mountain, about eight miles southeast of Sheridan, in schists of the Cherry Creek series. It forms no prominent outcrops and disintegrates readily into reddish brown fragments and garnetiferous sand. In a hand specimen the only recognizable mineral is a deep red variety of garnet which occurs in rounded grains about one millimeter in diameter. Examination in thin section shows the constituents, with their approximate percentages, to be garnet (45%), omphacite (40%), quartz (10%), and magnetite (5%).

The garnets appear as rhombic dodecahedrons, free from inclusions, fresh and unaltered, and with well rounded outlines. The omphacite is the grass-green variety of pyroxine which occurs only in this rather rare rock called eclogite. In the thin section examined it appears quite fresh and contains numerous inclusions of quartz, garnet, and magnetite. Magnetite occurs as idiomorphic crystals and also as narrow streaks along cleavage lines in the omphacite. The minerals show a tendency toward elongation in one direction, probably as the result of stress conditions at the time of crystallization. The order of crystallization, or of their ability to form in idiomorphic outlines, is garnet, omphacite, and lastly quartz which is entirely xenomorphic and merely fills the interstitial spaces.

The term eclogite was first used by the French petrographer Haüy, more than a century ago, to designate a rock composed chiefly of green augite and garnets. Geologists are not entirely agreed as to the derivation of eclogites, but the general opinion seems to be that they are formed from basic eruptives of the gabbro type.

So far as the writer is aware the only other rocks in North America described as eclogites occur in California.¹

Laramide Intrusives

The Tobacco Root Batholith

General Character.- The name Tobacco Root Batholith is suggested as a convenient name for the mass of quartz monzonite which occupies about 100 square miles in the central portion of the area. It has an irregular outline with the greatest dimension extending in a northwesterly direction for about 19 miles. The eastern boundary lies about $3\frac{1}{2}$ miles west of the Madison River and the western edge projects about a mile beyond the South Boulder valley. An opportunity to observe the contacts in vertical section is afforded by some of the larger cirques. Most plutonic masses of this type have been described as having steep walls and no observable bottom, and, as far as could be learned, the Tobacco Root Batholith agrees with this description.

Outliers, probably having underground connections with the main mass, are distributed around the batholith at numerous points. There is one two miles west of Pony and a much smaller one three miles south of Red Bluff. Others occur at the head of North Meadow Creek, at the head of Branch Creek, near Mill Creek $3\frac{1}{2}$ miles northeast of Sheridan, and at least three separate masses outcrop on Bear Gulch. It is very likely that much of the remaining part of the area is underlain by granite which has not yet been uncovered by erosion.

The whole intrusion is, no doubt, part of the much larger Boulder Batholith which extends as far east as Silver Star, or to within about seven miles of the Bear Gulch outliers. This inter-

¹Rulif S. Holway, "Eclogites in California," Jour. Geol., Vol. XII, 1904, pp. 334-358.

vening distance is covered with alluvium deposited in the Jefferson Valley. Because of lithological similarity, which will be considered later, and its surficial relation to the Boulder Batholith it is believed to be a satellite of this larger mass. The Boulder Batholith is of late Cretaceous or early Eocene age¹ and the Tobacco Root Batholith is assumed to be the same. The youngest rocks intruded by it are the lower Paleozoics which are cut by the Bear Gulch outlier.

Marginal contacts of the batholith are, in some cases, fairly sharp, while at other points there has been an infiltration of magmatic material from the invading rock resulting in a transition zone. In the district west of the town of Pony the contact is generally well defined, but south of Pony, near South Willow Creek, it is seldom clearly marked. Typical contact metamorphic minerals have been developed at some points but seldom extensively. West of Pony epidote has formed in a hornblende schist; near Granite Peak, at the head of South Boulder Creek, there is considerable development of tremolite in quartz-feldspar gneiss. Contact action has been most marked on the southwest border of the batholith where garnets of unusual size have been developed in rocks of the Cherry Creek series.

Petrography of the Main Mass.- The main mass of the intrusion varies from a fine to coarsely granular texture, occasionally becoming porphyritic. A convenient exposure of the coarser variety is well shown on the road-cut of the main highway about $5\frac{1}{2}$ miles north of McAllister. Feldspars attain a length of two inches and hornblend crystals about one inch. Porphyritic phases, having large feldspar phenocrysts, occur south of Cataract Creek

¹Paul Billingsley and J. A. Grimes, "Ore Deposits of the Boulder Batholith," T.A.I.M.E., Vol. 58, 1918, p. 287.

near Pony, and also about two and one-half miles south of Revenue. The large feldspars are more resistant to weathering than the other constituents and at the Revenue exposure many well shaped crystals lie scattered about the ground. The relatively fine grained type, in which crystals average about $1/8$ inch in size, is most common.

Corresponding to textural changes there are compositional changes as the rocks pass from a central granitic belt to an outer granodiorite or diorite zone. Probably all gradations exist between the granitic rocks which contain a marked excess of orthoclase over plagioclase, and granodioritic rocks in which the reverse is true. Only the granitic rocks are porphyritic, and they exhibit the coarsest textures. There is a general gradation in passing from granite through quartz monzonite and granodiorite to diorite. Diorite and granodiorite occur only at, or close to, the contact, but this outer zone may be very narrow, as in the area north of McCallister.

Depending upon compositional changes there are changes in color from pink, which takes on a deeper tone on the weathered surface, in granites, to mottled gray in diorites.

From Revenue, westward through Potosi to the head of North Willow Creek, most of this central portion is a true granite. A specimen collected from a uniform mass two and one-half miles south of Potosi seems to be fairly representative. Megascopically it is a medium grained, pale pink colored, rock in which all the essential constituents are clearly recognizable. Under the microscope the texture is typically hypautomorphic granular, and the constituents are orthoclase (45%), basic oligoclase (25%), quartz (14%), hornblende (7%), biotite (4%); accessory titanite (2%), magnetite (2%), apatite (1%), with a few crystals of zircon and a

little magnetite. Secondary chlorite, kaolinite, sercite, and titanite are present. Large orthoclase crystals poikilitically enclose oligoclase; both are slightly clouded by alteration products. Most of the orthoclase is somewhat perthitic. Hornblende is the ordinary green variety and is partly altered to both biotite and chlorite and both the primary and secondary biotite are chloritized. Titanite is present in a few large wedge shaped crystals and also as a secondary mineral derived from titaniferous magnetite. Quartz is in rounded blebs or fills the interstitial spaces between feldspars.

Anywhere along this central belt similar rocks will be found having only slight variation in character. The amount of orthoclase may be greater, as in the case of the porphyritic variety south of Revenue; Biotite and hornblende are always present, either may be in excess but more commonly it is biotite, and the combined amounts will not exceed 15 per cent of the total. A very little muscovite may be present as in the rock at Potosi Hot Springs. These are only minor variations so that the rock may still be classed as a granite.¹

In passing from the granitic belt toward the outer margin of the intrusion there is a decrease in the amount of orthoclase relative to plagioclase, that is from granite through quartz monzonite to granodiorite. The plagioclase feldspar becomes andesine, but other constituents have the same characteristics as described for granite, and are present in both the same quantities.

Quartz monzonite forms the country rock at the Garnet mine, on Cataract Creek and is also well exposed in the surface

¹Albert Johannsen, Descriptive Petrography of Igneous Rocks, Vol. I, 1931, pp. 140-158.

one-fourth mile north of the mine workings.

Typical granodiorite occurs near the Bismark mine in the broad tongue extending from the main mass westward across South Boulder Creek. In the hand specimen it is buff colored, rather fine grained, even textured rock. In addition to feldspar, which forms the bulk of the rock, hornblende crystals one-fourth inch long, and a few blebs of quartz can be recognized. In this section constituents were identified and percentages determined as follows: Andesine (60 %), orthoclase (20 %), quartz (10 %), hornblende (4 %), biotite (3 %), with accessory titanite, magnetite, apatite, and zircon making up the remaining 3 per cent. Secondary chlorite, sericite, yellow iron oxide, and calcite are present. No features of particular interest are presented.

In summarizing the variations in these gradational types a few differences and similarities may be noted. Although plagioclase occurs in all it is zoned only in the rocks occurring toward the outer margin. Perthitic orthoclase is common in the granites and correspondingly rare in the granodiorites, whereas with micropegmatite the reverse seems to be true. Titanite and zircon occur throughout, but secondary titanite was observed only in the granite.

Marginal Phases.- At several points along the contact of the intrusive there are types which differ from the main mass considerably more than its various gradational phases differ from each other. The rocks of the main mass contain ten per cent or more of quartz and more than five per cent of potash feldspar, whereas at many points along the margin there is a narrow zone from which quartz and potash feldspar are absent or occur only in insignificant amounts.

North of Norris, in the vicinity of Norwegian Creek, the

outer zone is a diorite. Continuous exposures cannot be traced because of drift, but within a few hundred feet of the contact the rock is granodiorite.

Between Norwegian Creek and Norris lies a conical hill, a monadnock rising about 300 feet above the old erosion surface, composed of granodiorite. The margin of the batholith which passes quite close to the road is marked by a dark dioritic border phase, which again cannot be traced continuously, and which grades into the granodiorite of which the mound is composed within about one-fourth mile.

On the road cut of the main highway, about four miles north of McAllister, a meladiorite is exposed. Within about 300 feet almost every gradation can be found between this rock and granite. The different phases occur as schlieren. Contacts will be sharp at one point and then within a few dozen feet the same rocks may be seen to grade into each other. More than half the meladiorite consists of hornblende and biotite, the remainder being andesine. By decrease in the ferromagnesian minerals the rock becomes a typical diorite, and biotite, abundant in the darker rock, forms but five per cent of the total.

Similar rock occurs on the north side of Cataract Creek, about one and one half miles west of Pony. The outcrop, about 200 feet in diameter, is very noticeable due to the strongly contrasting dark hornblende and white feldspar crystals. It is even textured with individual crystals ranging between five and fifteen millimeters in length. The mineral constituents are, hornblende (55 %), andesine (20%), quartz (10%), orthoclase (10%), biotite (4%), with magnetite and apatite as accessory minerals. The rock is best classed as a melagranodiorite.

Other rocks, identical in appearance, occur at the head

of the north fork of Mill Creek; on Bear Gulch; and at the head of the north fork of Meadow Creek.

The dioritic phases just described are localized and do not form a continuous belt around the intrusive. There is no diorite southeast of Pony, in the vicinity of Willow Creek, nor around the southeast margin of the batholith, nor west of Cataract Creek. At these points the edge of the intrusive is not more basic than granodiorite.

The dioritic phases may have differentiated in place and formed only at these widely separated points or, as is more probable, they may have formed all around the outer margin during an early stage but have been completely assimilated at some points by later surges of the more acid magma. As previously noted there is usually a gradation from basic marginal phases to more acid varieties, but at some points, north of McAllister, for example, contacts are sharp. The further possibility that the diorite differentiated at depth and was later intruded seems unlikely since fragments of diorite are contained in granodiorite and are cut by it, but the reverse relation was not found.

Marginal assimilation cannot be appealed to as an explanation of these marginal variations. In the border phase the amount of quartz is always low, probably never above five per cent, while the invaded rocks are gneisses and schists high in quartz. In the few cases where blocks of gneiss are found as inclusions their boundaries are very little altered, edges are sharp and angular, indicating little assimilative action.

Along the southern boundary of an apophysis of granodiorite which extends westward from the main mass toward the confluence of Curly and South Boulder creeks, is a zone of hydrothermally altered rock varying in width from 50 to 160 feet, striking east-

west and dipping about 70 degrees to the south. Workings of the Atlantic and Pacific prospect are confined to this body and have exposed it at points on the surface over a distance of 1500 feet. The northern boundary is marked by faults exposed in two tunnels and the southern boundary, although not actually exposed, can be placed closely by means of pits. Megascopically the rock has a light gray bleached appearance having quartz and feldspar as the only identifiably minerals. Under the microscope the constituents, with their approximate percentages, are quartz (50%), orthoclase (35%), ologoclase (13%), the remainder being pyrite. White mica and kaolin are secondary.

The absence of ferromagnesian minerals and the very fine grained appearance at once suggest aplite, but the texture is more like that of a protogene granite. There is almost no variation in texture over the entire 160 feet exposed in the prospect adit, so that if it is an aplitic differentiate the fineness of grain must be due to some factor other than rapid cooling, probably to escape of mineralizers. There has been much fracturing, as fine seams of quartz and knife-blade veinlets of pyrite traverse it in all directions.

Inclusions.- Inclusions of a dark gray, basic dioritic rock are common in the granite of the Boulder Batholith.¹ This granite is used in Butte as a building stone and many blocks show such inclusions. They may be seen in the steps of the main building of the School of Mines. Inclusions of the same type are locally common in the Tobacco Root Batholith. They vary in size from an inch to three or four feet, are rounded or subangular

¹W. H. Weed, Geology and Ore Deposits of the Butte District, Montana, Prof. Paper 74, 1912, p. 32.

Billingsley and Grimes, op. cit., p. 289.

N. H. Winchell, op. cit., p. 150.

in form, and resist weathering to a greater degree than the enclosing granite, so that they frequently form rough projections on the surface. They are larger and more numerous near the margin of the intrusive. In color they are dark gray, and although the texture varies somewhat, the composition seems always to be dioritic, corresponding to the rock found around the outer edge of the batholith. They undoubtedly represent cognate xenoliths of the earlier dioritic phase which, after solidification at depth, was shattered and fragments incorporated as inclusions in the parent magma from which they originally separated. They are quite distinct from xenoliths of gneiss, in which the banding is still plainly visible.

Outliers.- Outliers, which are probably but upward extensions of the margin of the batholith, now exposed by erosion, occur at several points.

One of these is the dioritic intrusion, a little less than a square mile in area, located two and a half miles northwest of Pony. It is fairly uniform in composition, but the texture is variable. In the hand specimen it is a dark gray rock having hornblende and feldspar as the chief constituents; individual crystals averaging about three millimeters in length. The constituents, with approximate percentages, as determined under the microscope are, andesine (55%), hornblende (30%), biotite (5%), orthoclase and quartz (5%). Accessory minerals magnetite, apatite, and titanite together form about five per cent. The texture is hypautomorphic granular, as in typical diorites. The feldspar is much more strongly zoned than in the granodiorite of the main mass, but it is otherwise similar. The hornblende differs in being of a paler greenish color, having more frequent twinning, and always having ragged outlines.

On the divide between Charcoal Creek and Pony Creek, in the southeast quarter of section 10, T.2S, R.3W, along the border of the intrusive, and in an apophysis extending into the gneiss, slender, needle-like hornblende crystals arranged in roughly parallel orientation attain a length of two inches or more, but the feldspars are no larger than in the normal phase. Other differences are noted when examined in this section. In addition to subparallel arrangement, the hornblende presents a decidedly more ragged outline. Many feldspar crystals have their own outline against the hornblende and often project into it, indicating that the hornblende continued to grow after some of the feldspar had ceased crystallizing. Magnetite is present in greater amount and much of it occurs as trains of tiny crystals arranged along the central portion of the long hornblende parallel to its length. (Pl. 6, Figure F.).

The constrained magma probably crystallized under directive pressure. The hornblende began crystallizing early and continued after some of the feldspar ceased and during that time it grew most rapidly in the direction of least pressure. The linear arrangement of the magnetite dust is due to its having been included by the early forming hornblende and as this mineral continued to crystallize it attempted to rid itself of the excess iron.

Along the southern border, on Charcoal Creek, where the diorite has been cut through by a prospect tunnel, there are inclusions of gneiss oriented in all directions in a dioritic matrix forming an igneous breccia.

Other small dioritic outliers occur three miles northeast of Sheridan, seven miles southeast of Sheridan at the head of Branch Creek, and on Bear Gulch.

Relation of the Tobacco Root Batholith to Other Masses.

The Boulder batholith, with an area of 1100 square miles, lies 150 miles east of the great Idaho batholith whose surface is exposed over an area of 20,000 square miles.¹ These were generally thought to be parts of the same mass, but Ross² believes the Idaho batholith to be much younger. Irregularly distributed around the Boulder batholith are several smaller bodies, (Fig. 2) whose compositions do not differ greatly from the larger mass, of which the Marysville batholith lying six miles north, the Phillipsburg batholith thirty-five miles west, the Elkhorn batholith ten miles south, and the Tobacco Root batholith nine miles southeast, are examples. Because of chronological data, lithological similarity, or field relations are all generally regarded as being parts of the same mass, whose irregular upper surface has been exposed in varying degrees, at different points, by erosion. Probably all were intruded within the same geological period, but whether simultaneously or not is unknown.

Normal rock types from the Boulder batholith are quartz monzonites and cannot be distinguished in the field from those of the Tobacco Root area, and the mass shows similar changes toward its margins.

Toward the margins of the batholith the rock becomes somewhat finer grained and equigranular, as noted south of Helena, east of Boulder, and other localities. The rock apparently becomes more basic and the eye is at a loss to surely distinguish quartz monzonite from such modifications as granodiorite and quartz diorite. At certain localities, as verified by the microscope, the rock becomes dioritic in character.³

Detailed studies of the Marysville batholith have shown it to be a quartz diorite, and it is accomplished by smaller

¹J. B. Umpleby, "An Old Erosion Surface in Idaho," Jour. Geol., Vol. 20, 1912, p. 145.

²C. P. Ross, "Mesozoic and Tertiary Granitic Rocks in Idaho," Jour. Geol., Vol. 36, 1928, pp. 573-693.

³Adolph Knopff, "Ore Deposits of the Helena Mining Region, Montana," U.S.G.S. Bul., 527, 1913, p. 30.

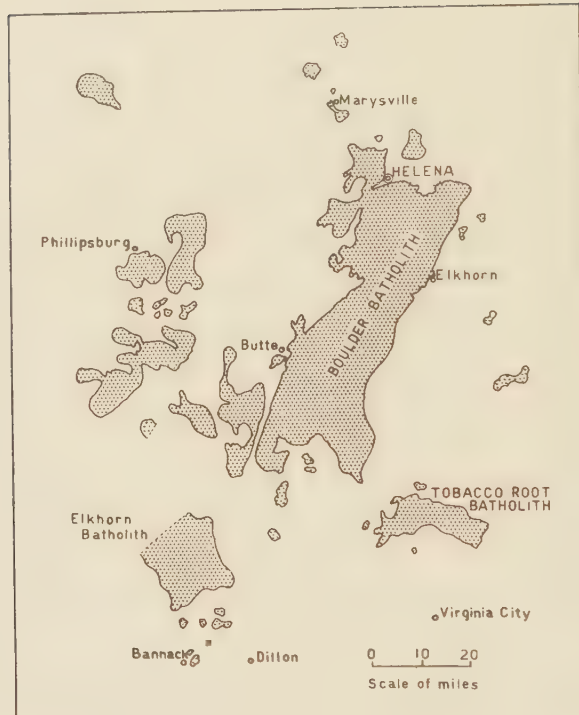


Figure 2

Sketch showing relation of Tobacco Root batholith to Boulder batholith. (After Billingsley)

dioritic masses, although some satellitic chimneys are not to be distinguished from the main mass.¹

The general character of the Phillipsburg batholith is probably granodiorite, and smaller outlying masses are diorite.²

Winchell has called the Elkhorn batholith quartz monzonite. No outlying masses are mentioned.³

Similar to these is the Tobacco Root batholith whose average composition is probably close to quartz monzonite, and it is also accompanied by smaller and more basic outlying masses.

For comparison, the mineral compositions of some of these related areas are tabulated below. All figures represent weight per cent.

¹ Joseph Barrell, "Geology of the Marysville District, Montana," United States Geological Survey, P.P. 57, 1907, p. 54.

² W. H. Emmons and F. C. Calkins, "Geology and Ore Deposits of the Phillipsburg Quadrangle, Montana," United States Geological Survey, P.P. 78, 1913, pp. 84 and 97.

³ A. N. Winchell, op. cit., p. 169.

	1	2	3	4	5	6	7	8
Quartz	22.9	22.5	30.4	15.18	11.10	20.7	22.2	13.3
Orthoclase	21.1	22.4	21.2	13.34	24.46	24.2	15.6	33.9
Andesine	37.0	33.9	32.7				47.5	40.6
Albite				27.77	24.63	23.0		
Anorthite				20.02	19.19	17.8		
Biotite	10.9	10.9	9.0				7.2	2.7
Hornblende	3.6	7.2	5.3				5.5	7.6
Diopside				7.97	4.48			
Hypersthene				9.41	11.28	6.4		
Magnetite	1.9	1.5		3.71	3.48	3.5	1.7	1.2
Hematite			1.3					
Ilmenite	.5			1.22		1.4		
Titanite		.4	.1				.1	.3
Apatite	.3	.3					.2	.4
Calcite		.3						
Water, etc.	1.1	.5	.1			1.0		
	99.3	99.9	100.1	98.62	98.61	100.1	100.0	100.0

1. Biotite-hornblende-quartz monzonite. Butte, Montana.
2. Biotite-hornblende-quartz monzonite, Alice mine, Butte, Montana.
3. Biotite-quartz-hornblende monzonite, Homestake, Montana.
4. Biotite-hornblende granodiorite, Bannack, Montana.
5. Mica diorite, Elkhorn district, Montana.
6. Augite-biotite-hornblende-quartz monzonite, Elkhorn, Jefferson County, Montana.
7. Quartz diorite, Marysville, Montana.
8. Hornblende-biotite-quartz monzonite, Tobacco Root Mountains, Montana.

Analyses 1, 2, 3, and 6 were computed by Winchell¹ from the complete chemical analyses and show the approximate modal mineral composition. The plagioclase was calculated to Ab₅₅An₄₅, and surplus soda added to the orthoclase.

Analyses 4 and 5 were calculated by P. J. Shenon, Bul. 6, Montana Bureau of Mines and Geology, page 20, 1931, and show the pure molecules orthoclase, albite and anorthite.

Analysis 7, calculated by Barrell, is the mode determined by the Rosiwal method of analysis. The feldspar was merely called

¹Winchell, op. cit., p. 36.

plagioclase in the original determination but is here shown as andesine for convenience in comparison and this is sufficiently accurate.¹

That from the Tobacco Root area, shown in the last column, is the average of six specimens determined by Rosiwal's method of analysis.

These data show the similarity of composition existing between the intrusives. In all cases plagioclase is the dominant constituent, ranging from 33 to 47 per cent: orthoclase is next in importance constituting from 13 to 34 per cent, and quartz has almost the same range. Ferromagnesian and accessory minerals are everywhere about the same.

The Tobacco Root batholith appears to have slightly less quartz, but it has a correspondingly greater amount of orthoclase. The total amount of feldspar is a little more and the ferromagnesian minerals a little less than in the other analyses.

When the amounts of quartz, orthoclase, and plagioclase in each sample is plotted on a triangular diagram (Fig. 3), the result is not a haphazard distribution. All analyses from the large Boulder batholith proper clearly belong in one group, having more quartz than the others, and containing plagioclase to orthoclase in the approximate ratio of 3 to 2. The four remaining samples are divided evenly into two groups. The two bodies which are larger and closer to the main mass correspond more nearly to it in composition: the smaller outlying bodies are more basic. All are very probably parts of a single intrusive unit whose outer margins became more basic by differentiation processes and are now exposed in this manner because of their distance from the center of differentiation.

¹Joseph Barrell, "Geology of the Marysville Mining District," United States Geological Survey, P.P. 57, 1907, p. 56.

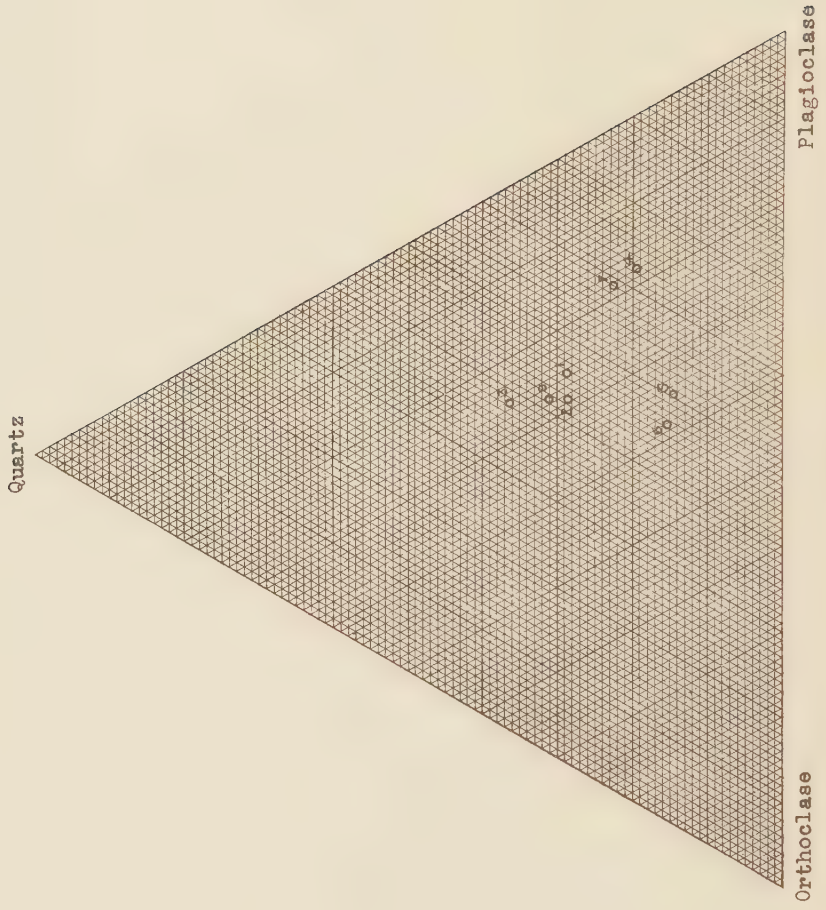


Fig. 3.

Associated Rocks.- Probably all hypabyssal rocks of post cambrian age are related to the granitic batholith or to the much younger lava flows, but it is not always possible to separate them. Sometimes pegmatites, aplites, and quartz veins can be traced directly into the granite, and likewise some of the diabase dikes may be traced into the basalt, but there are dikes of intermediate composition which cannot be traced in this manner and may have differentiated from either source.

a. Granite pegmatite.

Locally, over a small area, the ground may swarm with granite pegmatite dikes; such a point is the divide between Barton and Alder gulches, east of the Barton Gulch mine. They are nearly white, coarsely crystalline, unfoliated rocks, composed almost entirely of quartz and feldspar. Many show fine intergrowths of quartz and feldspar producing the variety known as runite. Certainly most of these pegmatites originated from the Tertiary granite, but fragments of similar rock are said to occur in conglomerate of Belt age.¹

b. Aplite.

Although aplite is less frequent than pegmatite it is, nevertheless, quite common. It presents no features of particular interest and ordinarily consists of quartz, microcline, orthoclase, plagioclase, usually in this order of abundance, with perhaps a few small flakes of biotite. Apatite, magnetite, and zircon are the common accessories.

c. Quartz blowouts.

Probably no better term can be used to describe the widespread occurrence of certain masses of quartz than the prospector's term "quartz blowouts." They are irregularly shaped masses or

¹E. S. Perry, Montana School of Mines, Personal communication.

veins, sometimes 150 feet in width, having every possible orientation. Some apparently consist solely of quartz, others are largely quartz with occasional masses of potash feldspar a foot or more in diameter. Evidently they represent final exudations from the consolidating granite as they increase considerably in numbers as the periphery of the granite is approached. Although many prospect pits have been sunk in them, few are mineralized at all and none so far found are of economic importance.

d. Alaskite.

Along the highway about 3.5 miles south of Ruby, on Ruby Creek, is a small mass of rock, some 200 feet across, which when examined under the microscope was found to be alaskite. It is a fine grained, massive rock, containing microcline, quartz, albite, orthoclase, and a few flakes of biotite.

e. Kalialaskite porphyry.

Anyone passing north along the main highway from Sheridan to Twin Bridges, viewing the range to the east, could scarcely fail to observe what is the most prominent sill in the district. It can be seen for several miles, appearing as a broad reddish band, passing over the top of Old Baldy Mountain. It is well exposed on the steep southeast slope of the mountain striking northeast and dipping westward where it is estimated to be about 300 feet thick. It has generally been intruded below the Flathead formation (basal Cambrian), but some large fragments of the Flathead formation are also found at the bottom of the sill. As observed in the field the rock is a porphyry with phenocrysts of white feldspar ranging from $1/8$ to $3/8$ inch in length, and frequently showing twinning, embedded in a fine grained reddish-brown ground mass. On a deeply weathered surface the whole rock takes on a more sombre hue and the phenocrysts become difficult

to distinguish. The reddish color is due to finely disseminated primary iron oxide. Under the microscope the texture is porphyritic holocrystalline. Large idiomorphic crystals of orthoclase are enclosed in a fine-textured ground mass of feldspar and quartz. The approximate composition is orthoclase (58%), quartz (40%), the remaining 2 per cent being magnetite, apatite, and hematite. The feldspar is clouded with kaolinite and secondary white mica.

f. Microgranite.

At the Mammoth property on South Boulder Creek, located about one-half mile above the office buildings, is a very fine-textured, grayish-black dike rock which resembles a diabase in appearance. It contains small amounts of pyrite and galena and is traversed by many thread-like veinlets of calcite. The texture is much finer than a normal granite and the proportion of dark minerals, mostly biotite, is higher but otherwise it is a true granite.

g. Granodiorite porphyry.

Dikes of this type, though prominent in most parts of the area, are much more numerous near the granite contact.

The divide separating the heads of Wisconsin and Dry Boulder creeks has been reduced by ice action to an arete, which, at its lowest point, is but a few feet wide, and composed only of a granodiorite porphyry. This dike, with a width of 20 to 50 feet, may be traced eastward with some interruptions across Lake Shore Peak into the cirque at the head of South Boulder Creek. Megascopically, prominent phenocrysts of white plagioclase feldspar are seen to be enclosed by a greenish-gray fine-textured ground mass. Under the microscope the constituents, with approximate percentages, were found to be oligoclase (35%), quartz (30%),

orthoclase (15%), biotite (5%), hornblende (10%), with accessories (5%) of apatite, magnetite, titanite, and pyrite. The microscopic texture is hypidiomorphic prophyritic with oligoclase occurring as idiomorphic crystals, showing pronounced zoning, embedded in a finer mass of feldspar and interstitial quartz. The other minerals show no unusual features.

Another granodiorite dike occurs at the Agitator and Concentrator mining claims on Mill creek and can be traced for about one-half mile southwest to Corral Gulch. It is very similar to the previous dike except for sporadic quartz phenocrysts, which occasionally reach 3/8 inch in diameter, and numerous specks of pyrite. The dike averages 35 feet in width, is nearly vertical and strikes N. 15° E.

Another very similar granodiorite dike lies one mile southwest of the Smuggler mine, between Mill and Ramshorn creeks. It is also vertical and strikes north-south. Again, at the base of Cambrian formation on Porphyry Mountain, near Bear Gulch, is a thick sill of the same rock.

On Wisconsin Creek, near the Noble mine, a leucogranodiorite and a melagabbro dike hold a nearly parallel trend, in a northeasterly direction, for about one and one-half miles. Both dip steeply to the north, the acid rock being on the lower side. Although they converge toward the southwest they were not seen in contact. The leucogranodiorite is a light gray, fine-textured, porphyritic rock with phenocrysts of quartz and feldspar seldom more than one-fourth inch in length. Highly zoned oligoclase makes up more than half the rock; the dark constituents, biotite and hornblende, are very sparse.

h. Melagabbro.

The rock associated with the above dike is a melagabbro.

In the hand specimen it very much resembles the hypersthene gabbro occurring near the Frisby mine. It is a fine-grained, greenish black to black, massive rock which, under the microscope, exhibits a subophitic texture with automorphic labradorite laths occasionally penetrating larger brownish-green grains of diopside. Olivine is abundant in both large and small rounded grains which are usually bordered by an inner rim of magnetite and this, in turn, is surrounded by an outer rim of platy antigorite. The central portion of the crystal is usually traversed by a network of cracks showing yellowish serpentine alteration. Deep brown biotite with scalloped or ragged edges is intergrown with both diopside and labradorite. Magnetite and apatite are accessory constituents, the former becoming locally abundant.

The leucogranodiorite and the melagabbro may very well be complimentary dikes. The repeated occurrence of a syenitic rock with a dark basic rock is mentioned by Peale in a district about 60 miles northeast of this,¹ and although the rocks may not be identical lithologically, it is interesting to note the association again, and that in this case, as elsewhere, the dark basic rock is uppermost but the relation of one to the other is not clear.

1. Syenodiorite porphyry.

On South Boulder Creek, about 4 miles below Mammoth, a sill like mass, having the composition of syenodiorite, has been intruded at the base of the Cambrian formation. It is a compact light gray rock with abundant phenocrysts of pink feldspar about 1/8 inch in length, and fewer but larger phenocrysts of quartz. Under the microscope the rock appears very much altered but was found to consist of andesine and quartz with a small amount of hornblende. The dark minerals are in such small proportion that

¹A. C. Peale, op. cit.

the prefix leuco might be added to the name.

j. Syenogabbro.

On the north side of California Gulch, about five miles east of Laurin, there are two prominent dark greenish gray dikes, varying in width from 100 to 200 feet and striking northwest, about one and one-half miles apart. Following the same line of strike similar rock is encountered on Branch Creek and again on Ramshorn Creek. The dikes converge toward the north as they are less than half a mile apart at the latter point; farther north they disappear beneath the lake beds. At many points where they do not actually outcrop their presence is betrayed by the dark brown soil, characteristic of its weathering products, and these distinctly colored bands can sometimes be followed by eye across the hills for a mile or two. In this manner the dikes are traceable for seven miles. Under the microscope the constituents, with their estimated percentages, are found to be diopside (50%), labradorite (25%), orthoclase (10%), hornblende (8%), quartz (5%), accessory magnetite, apatite, (2%). The texture is hypautomorphic granular in which irregularly shaped diopside crystals of pale brown tint are intergrown with labradorite. Much of the hornblende is secondary after pyroxene. Quartz occurs mostly as micrographic intergrowths, but some fills interstices between pyroxene and feldspar. A little sericite and chlorite have been formed but generally the rock is quite fresh.

k. Gabbro.

Plutonic rocks of gabbroic character are not common in the area, but there is one mass of this type exposed over an area of about three-fourths mile in extent at the head of North Meadow Creek, near the Frisby mine.

It is a dark gray to black, medium-grained, massive rock

showing pyroxene, pyrite, and magnetite in the hand specimen. Schiller structure is sometimes prominently developed. From an examination of thin sections, under the microscope, it seems that most of the mass may be classed as a hypersthene bearing olivine gabbro, although olivine was not present in every slide. The general texture is hypautomorphic granular, but near contacts it is subophitic and is much finer grained. The greater part of the rock is composed of pyroxene and labradorite, with the former slightly preponderating. Pyroxene occurs as pale greenish-brown, irregularly shaped grains of hypersthene and diopside, and they are always associated. Many individuals of both species show a narrow dark shadowy rim located near the outer edge and completely surrounding them. It may be due to magnetite dust developed during a changing crystallization period. Labradorite occurs in smaller well twinned crystals, most of which either crystallized later or continued to crystallize after the pyroxene. Occasional plates of deep brown biotite are intergrown with pyroxene and are slightly altered to chlorite, but on the whole the rock is quite fresh. Small amounts of pale green hornblende occur similarly. Olivine is present in a few relatively large rounded grains. It is slightly altered to iddingsite along a network of cracks and often has quite a thick, continuous rim composed of an aggregate of hypersthene crystals. Magnetite may become so abundant locally as to compare five to ten per cent of the rock, and it is occasionally surrounded by a rim of secondary titanite. A small amount of pyrite, zircon, and apatite is irregularly scattered through the sections. A little secondary calcite also occurs.

This intrusive undoubtedly bears a genetic relation to mineralization at the Frisby mine, but its relation to the granite batholith is uncertain. On the north side of the road one-half

mile below the camp buildings, where relations are not quite clear, a basic dioritic rock which shows some affinities to the gabbro, has been intruded and shattered by granodiorite. (Pl. 4, Fig. C). Also a granodiorite dike about fifteen feet wide, cuts the main gabbro mass one-fourth mile southeast of the camp buildings. The gabbro may be an earlier differentiate of the granite, intruded by still later acid differentiates.

1. Epidosite.

A vertical dike of epidosite, about four feet in width and striking north-south, outcrops about 500 feet above the adit of the Chromite prospect on Horse Creek. Veinlets of this material are not uncommonly associated with some of the highly metamorphosed limestone but this is so large and so far distant from any known igneous outcrop as to attract attention. It can be traced only a few feet up the steep hillside before becoming covered by debris. It is light greenish colored, very finely granular, compact rock showing numerous spots of yellow iron stain on the weathered surface. Under the microscope it appears as a aggregate of irregularly shaped, interlocking epidote crystals with a very little interstitial quartz and sparsely scattered magnetite and garnet grains. The magnetite shows slight alteration to hematite but otherwise the rock is quite fresh. Whatever the original character may have been it has been effectively obscured by the very complete epidotization, for no trace was found of other minerals.

Extrusive Rocks and Associated Dikes

Extrusive rocks, consisting of andesite, rhyolite, basalt, and volcanic dust are found at widely separated localities within the area and are of different ages.

Andesite

On South Boulder Creek, in T. 1 S., R. 3 W., Sect. 2, there is a small exposure of lava which may correspond in age to the Livingstone formation; in any case it antedates the Bozeman lake bed formation. Here sheets of andesite, basalt which is in part amygdaloidal, and rhyolite have been extruded in the order named. The most interesting of these is an andesite, locally known as "oatmeal rock" because of its unusual appearance caused by the elongate gray feldspars set in a dark gray aphanitic ground mass. The phenocrysts make up about fifteen per cent of the rock. Microscopic texture is holocrystalline porphyritic. Large well shaped and well twinned andesite crystals are embedded in a finely crystalline ground mass of andesine, hornblende, and a little interstitial quartz. There is considerable magnetite and a little apatite scattered through the slide. The whole rock is clouded with what appears to be magnetite dust in addition to normal alteration products. Hornblende is the yellowish-brown basaltic variety often showing prominently developed absorption rims. A mineral which at once attracts attention is of an unusually bright color, low relief, with an irregular platy outline. It is probably some chloritic alteration substance such as Vogelsang has termed viridite.¹

About one mile north of Virginia City there is a small outcrop of andesite, covering one-fourth square miles, which no doubt underlies the basalt although the actual contact is not visible. It is a light gray compact rock with feldspar phenocrysts up to 1/16 inch in length and sparse biotite flakes of similar size embedded in a dull gray fine-textured matrix of the

¹Albert Johannsen, A Descriptive Petrography of Igneous Rocks, Vol. 1, 1931, p. 195.

same material, containing a little magnetite and apatite. No unusual features were found under the microscope in the few thin sections examined, but Winchell,¹ who described the rock, found some of the phenocrysts to contain centers of calcite surrounded by unaltered feldspar as to suggest that the calcite is of magmatic origin. Similar rock occurs again on the east side of Alder Gulch about one-half mile below town and it also lies beneath basalt. The rock has been quarried and used locally for buildings. The Virginia City Museum which is constructed of andesite presents a very pleasing appearance.

Rhyolite

Gray and purplish gray aphanitic rhyolites occur as small isolated masses south of Red Bluff and north of McAllister. About three miles from McAllister, on south Meadow Creek, there is an exposure of rhyolite in which flow banding is so perfectly developed that it may easily be mistaken for bedding, in fact, the place is locally known as Slate Point because of the superficial resemblance this rock bears to gray slate. Rhyolite is exposed for 500 feet along the roadway on the west side of the creek. On the east side there is a smaller exposure of the same rock, but more massive, with only a trace of flow banding. As it is traced up the steep hillside all gradations form a massive rhyolite at the bottom, to a vesicular variety at the top of the section may be found. The tops of some hills, well above the rhyolite, are capped by basalt, but at no point could the contact between the two be found.

Inspection with the unaided eye shows only a purplish aphanitic rock with pronounced flow banding. In thin sections the microscope reveals a holocrystalline rock, of pilotaxitic

¹ Op. cit., p. 47.

texture, formed of minute feldspar laths and quartz containing a few small grains of magnetite.

Basalt

The largest single mass of basalt is that which caps the hills west of Virginia City and has an approximate area of 50 square miles. It is composed of many separate flows which have an aggregate thickness of well over 1000 feet near Virginia City, becoming thinner toward the north, and it is impossible to say just how much has been removed by erosion. Near Norris there is a remnant of basalt about half a square mile in area, approximately 300 feet thick, which dips northward at about 6 degrees. Similar rocks occur near Red Bluff, and another remnant of basalt occurs on Williams Gulch, southwest of Alder. Two small patches of basalt were also found on Horse Creek, 13 miles north of Virginia City.

The age of the basalt is not definitely known. The southern extremity of the large mass near Virginia City rests on Paleozoic formations. Toward the north it was extruded in part upon Bozeman lake beds of Oligocene-Miocene age, and in part upon the irregular surface of the Cherry Creek series. This well shown in the neighborhood of Virginia City. About a mile north of town basalt directly overlies the buff colored tuffaceous sediments of the Bozeman lake beds, and road cuts in the main highway at the eastern limits of the town show several feet of green and brown lake bed material below the basalt. About a mile south of town, on both sides of the gulch where it has been exposed partly by erosion and partly by the efforts of the early placer miners, basalt may be seen directly overlying schist and gneiss of the Cherry Creek series. On Williams Gulch it directly overlies lake bed material. Near Virginia City lake bed material

has been found beneath basalt at elevations much higher than those at which it was originally deposited. As it is poorly consolidated material and would rapidly waste away, the basalt must have covered it soon after the uplift occurred. This uplift could not have occurred after the basalt was extruded or it would show much more deformation than it does, and nowhere does the basalt show more than gentle warping. After the lake beds were deposited there must have been time for uplift and some little erosion before extravasation of the basalt, and this probably took place in Pliocene time.

The basalt once extended over a much larger area than at present but has since wasted away by erosion. It certainly did cover the lower portion of Alder Gulch in the vicinity of Virginia City and probably connected with the Williams Creek mass. This point is of importance because of phenomenal richness of the Alder Gulch placer ground and the possibility of equally productive gravel being buried beneath the basalt.

On a freshly broken surface the basalt is nearly black in color but when weathered may be dark gray or dull red. The texture may be fine and compact, or highly vesicular. Olivine in rounded grains up to 1/16 inch in diameter, is the only constituent visible to the unaided eye. Under the microscope rounded olivine crystals of variable size and augite with xenomorphic outlines occurs in a holocrystalline mass of lath shaped labradorite. Small grains of magnetite are always present.

In a fresh specimen incipient alteration of olivine is marked by a number of tiny and fairly regularly spaced cracks, forming a border around the grain; only a few of these cracks extend to the center of the grain and rarely do cracks cross it. A yellowish alteration product is more or less evident in all

these cracks, (Pl. 6, Fig. C). Peale¹ reports varieties of this basalt carrying quartz phenocrysts which show zonal bands of green augite. Whether these occur with olivine is not stated but it would not be expected, and since all specimens examined by the writer contained some olivine it is not surprising that no quartz phenocrysts were noted.

Tuff and volcanic dust is found interstratified with sedimentary beds of Cretaceous-Eocene age on South Boulder Creek and similar material is very common in Bozeman lake beds. However, the most interesting occurrence is a bed of volcanic dust from 6 to 12 inches thick which has been exposed by placer workings on Norwegian Creek. It is an ashy-gray, fine-textured, powdery material, in fact, it is so fine that practically all of it will pass through a 100 mesh screen. It is composed of shards, tiny particles of glass; rod-like, sharply angular, or scalloped in outline when viewed under the microscope. It lies but 5 or 6 feet below the present surface and, although volcanic material was not noticed elsewhere in this position, according to Mr. Alexander Leggat, of Butte, there are similar occurrences west of Butte.² This most recent expression of volcanic activity, but a few hundred of years old, was probably carried by winds from the southwest.³ The uniform fineness of the material indicates that deposition took place at a considerable distance from its source. Other volcanic ash beds in Montana are described by Rowe.⁴

¹Peale, op. cit.

²Personal communication.

³H. T. Stearns, "Craters of the Moon National Monument," Geog. Rev., Vol. 14, No. 3, 1924, pp. 362-372.

⁴Jesse Perry Rowe, "Some Volcanic Ash Beds in Montana," Bul. Univ. of Montana, No. 17, Geol. Ser. 1., 1903.

Diabase dikes.

The normal variety of diabase is common only around the edge of the basalt plateau near Virginia City. Being no more resistant than the invaded metamorphic rocks these dikes do not form prominent outcrops. Small olivine free dikes occur on the west side of Alder Gulch near its confluence with Spring Gulch, and at several points on Granite Creek. Most dikes, however, contain olivine which is visible in the hand specimen in small rounded grains. About a mile north and half a mile west of the intersection of Trail Creek and the highway a sample was taken from one of this type. Megascopically it is a very dark fine-grained dense rock typically diabasic in appearance. Microscopically the texture is holocrystalline subophitic with some tendency toward porphyritic development. Hypautomorphic crystals of pale brown augite are frequently wedged between automorphic laths of labradorite. Olivine occurs as rounded grains surrounded by rims of iddingsite and altered in this way along cracks. Small olive colored patches, evidently of some chloritic substance, are irregularly scattered through the slide. The frequency of diabase in proximity to the basalt suggest a common origin.

